RESEARCH DEPARTMENT

Long-distance tropospheric propagation measurements over the north sea at 774 MHz

RESEARCH REPORT No. K-182

UDC 621. 391. 812. 62. 029. 63 1966/46

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

LONG-DISTANCE TROPOSPHERIC PROPAGATION MEASUREMENTS OVER THE NORTH SEA AT 774 MHz

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UDC 621.391.812.62. 1966/46
029.63

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Section | Title | Page

SUMMARY 1

1. INTRODUCTION 1

2. TRANSMITTING AND RECEIVING SITE DETAILS 2

    2.1. Transmitting Site 2
    2.2. Receiving Sites 2

3. RESULTS 2

    3.1. Analysis 2
    3.2. Variations of Field Strength With Time at the Receiving Sites 4
    3.3. Field-Strength/Distance Curves 4
    3.4. Monthly Field-Strength Variations 5

4. COMPARISON OF 774 MHz OVERSEA RESULTS WITH OTHER MEASUREMENTS OVER THE SAME PATHS 7

    4.1. Band IV Measurements 7
    4.2. Comparison of Band IV and Band V Measurements 7
    4.3. Comparison of U.H.F. and V.H.F. Measurements 9

5. COMPARISON OF COMBINED BANDS IV AND V MEASUREMENTS WITH CCIR FIELD-STRENGTH/DISTANCE CURVES 9

    5.1. Adjustments Required to Standardize Measured Values 9
    5.2. Comparison Between Existing and Proposed CCIR Curves 11

6. CONCLUSIONS 12

7. ACKNOWLEDGEMENTS 12

8. REFERENCES 12

August 1966

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LONG-DISTANCE TROPOSPHERIC PROPAGATION MEASUREMENTS OVER THE NORTH SEA AT 774 MHz

SUMMARY

This report presents the results of field strength measurements on horizontally polarized u.h.f. transmissions at 774 MHz over the North Sea at distances from 198 km to 950 km. These measurements extended over a period of 2¼ years and have been used in the preparation of curves showing field strength as a function of distance for specified percentages of the total time.

The results indicate that for low time-percentages the field strength values vary greatly from month to month and from site to site; this is thought to be due partly to seasonal changes and partly to different meteorological conditions occurring over the different paths.

The monthly field strength values exceeded for specified time-percentages tend to be consistently higher during the summer months, as observed also during earlier measurements over the same paths at a frequency of 560 MHz. However, the highest values recorded throughout the present series of measurements occurred in a winter month.

The results are compared with earlier BBC measurements utilizing frequencies in the Broadcasting Bands II, III, and IV. It is deduced that there are no substantial differences between the present results and those obtained earlier on Band IV, other than those attributable to the measurements having been made over different periods of time.*

The resultant values obtained by combining the Band IV and Band V measurements are compared with both the existing CCIR curves, and with a modification of these curves which has been proposed by United Kingdom Study Group V, for u.h.f. propagation over the North Sea.

1. INTRODUCTION

V.H.F. and u.h.f. transmitters situated in the United Kingdom and Continental countries have to share the same television and sound broadcasting channels. Information is therefore required on oversea propagation so that the distance between stations can be planned to limit the probability of mutual interference during abnormal propagation conditions.

During the past decade the BBC with the co-operation of the Netherlands Postal and Telecommunications Services, have completed a series of long distance propagation measurements over the North Sea in the Broadcasting Bands II, III, and IV.[1,2,3] The results of these measurements were used in conjunction with data from other administrations to derive the CCIR (Geneva 1963)[4] oversea field-strength/distance curves. As a continuation of the oversea tests, Band V measurements were commenced on the 13th October 1961 and terminated on the 31st December 1963.

The transmitting station was at Scheveningen in Holland and measurements were made at five receiving stations situated on the east coast of the United Kingdom at distances ranging in length from 198 km. to 950 km.

* Broadcasting Bands:

Band I	41	MHz - 68 MHz
Band II	87·5	MHz - 100 MHz
Band III	174	MHz - 216 MHz
Band IV	470	MHz - 582 MHz
Band V	614	MHz - 854 MHz

2. TRANSMITTING AND RECEIVING SITE DETAILS

2.1. Transmitting Site

A BBC Research Department transmitter working on a frequency of 774 MHz was installed and operated by the Netherlands Postal and Telecommunications Services at Scheveningen Radio Station. Scheveningen is 13 m above mean sea level and is situated in latitude 52° 06′ N, longitude 4° 16′ E. The transmission was square-wave modulated at 1000 c/s to a depth of 100%. The modulation was cut for two seconds every minute for identification purposes.

The 774 MHz transmitting aerial was a corner reflector with an intrinsic gain of 13·5 dB relative to a $\lambda/2$ dipole, the half-power beam-width being ± 24°. The aerial was horizontally polarized and at a height of 47 m above ground level (a.g.l.). The direction of maximum radiation was 320° east of true north giving, in this direction, an effective radiated power (e.r.p.) of 0·95 kW. For all transmission paths the radio horizon was the sea.

The daily schedule of transmissions was 0830 - 2300 hours, British Local Time.

2.2. Receiving Sites

The receiving sites were those at which measurements were made during the previous experiments in Bands II, III and IV. Fig. 1 shows the geographical distribution of the sites and Table 1 gives additional receiving site details.

The type of receiver installed has been described in detail in earlier Research Department Reports.[5,6] The main features of the u.h.f. receiver were its high sensitivity and stability of calibration. The recording law was approximately logarithmic with a signal range of about 50 dB. This range was insufficient under certain conditions and an attenuator was switched into circuit between the r.f. and i.f. units when the recording milliammeter reached full scale deflection.

The 774 MHz receiving aerials comprised two tiers of ten-element Yagis; each aerial had an intrinsic gain of 12 dB, relative to a $\lambda/2$ dipole, and a half-power beamwidth of approximately ± 18°. At each receiving site the aerial was mounted 8·5 m a.g.l.

The recorder charts were run at a speed of 3 in. (76 mm) or 6 in. (152 mm) per hour depending upon the type of fading normally experienced at the site.

3. RESULTS

3.1. Analysis

The field strength recording charts were analysed on a daily basis, and then grouped into months, to give the overall data for each transmission path.

The records were analysed to determine the length of time during which signal levels exceeded various values of field strength at each of the receiving sites. These time durations, expressed as percentages of the total valid recording time, were then plotted against field strength in decibels relative to 1μV/m [dB(μV/m)] for an e.r.p. of 1 kW. The field strength exceeded for 0·1%, 1%, 5% and 10% of the total time was plotted against each of the distances at which the recordings were made. A family of curves was then constructed to show the field strength exceeded for different time-percentages as a function of distance.

TABLE 1

Receiving Site Details

LOCATION	DISTANCE FROM TRANSMITTER km	SITE HEIGHT ABOVE MEAN SEA LEVEL m	TRUE BEARING OF SITE FROM TRANSMITTER	LATITUDE	LONGITUDE
Happisburgh	198	15	295°	52°49′42″N	1°31′38″E
Flamborough Head	365	45	309°	54°07′39″N	0°05′40″W
Newton-by-the-Sea	543	20	317°	55°31′06″N	1°37′05″W
Bridge of Don	690	10	326°	57°10′40″N	2°05′00″W
Lerwick	950	90	342°	60°08′00″N	1°10′20″W

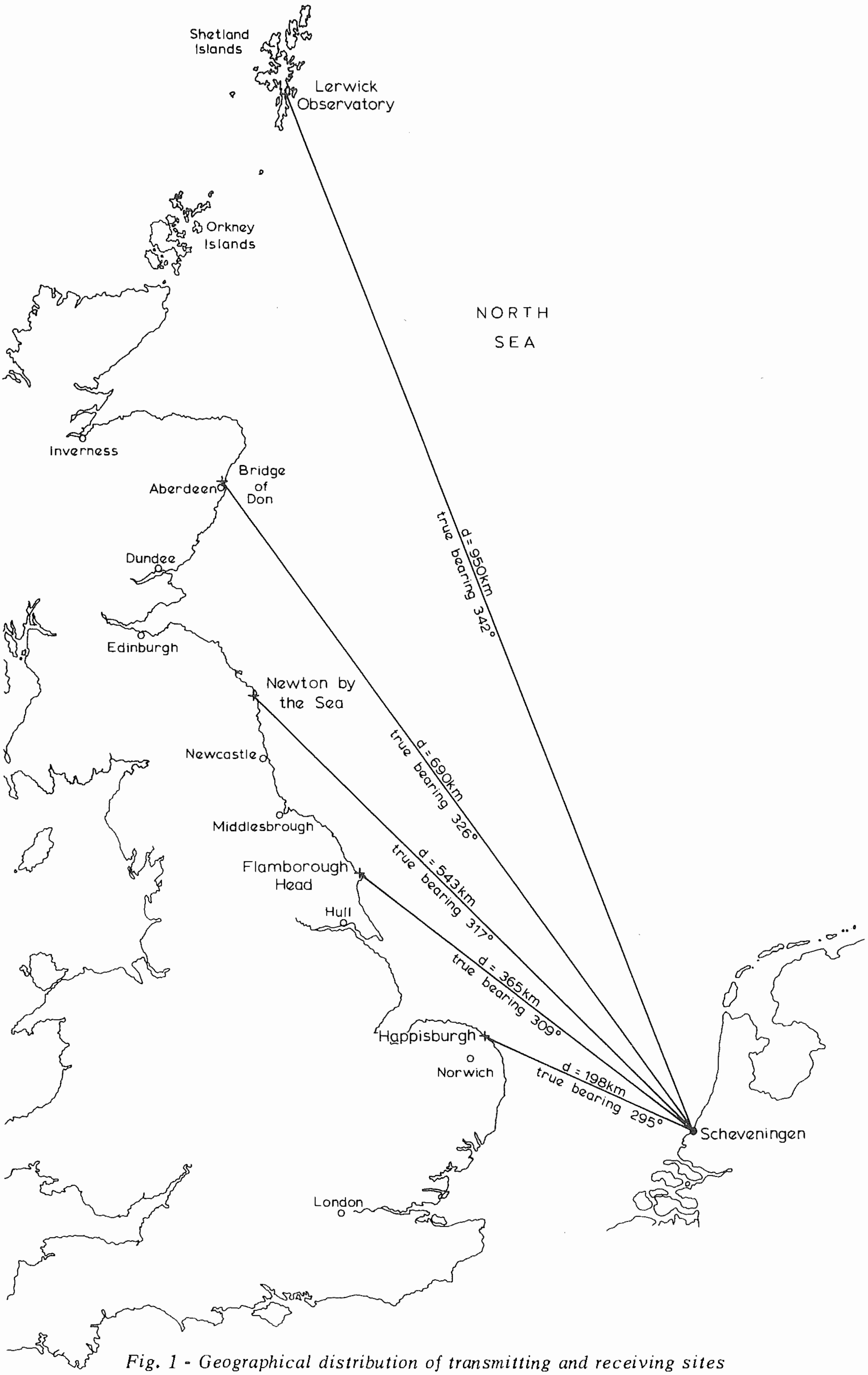


Fig. 1 - Geographical distribution of transmitting and receiving sites

3.2. Variations of Field Strength With Time at the Receiving Sites

The results of the measurements made at each of the sites are given in Fig. 2; these results are plotted as field strength exceeded against percentage of total transmission time. The table associated with Fig. 2 gives the total hours recorded at each site and the free-space field strength for each path.

It will be noted that the 0·01% field strength value for Bridge of Don (curve *d*) is lower than that for Lerwick (curve *e*), although Bridge of Don is nearer to the transmitter site. A possible explanation is that for this small percentage of the time the abnormal propagation conditions were less favourable for the Bridge of Don path than for the Lerwick path. The Lerwick site is, however, at a considerably greater height above sea level and this could also possibly cause significantly higher field strengths to be received under certain propagation conditions.

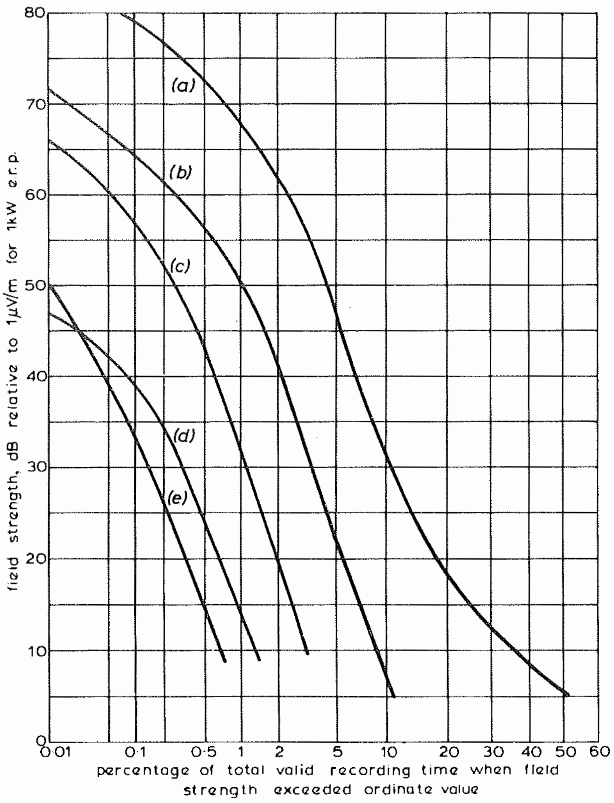
Table 2, derived from Fig. 2 gives the values of field strength exceeded for 0·1%, 1%, 5%, 10%, and 50% of the total time.

3.3. Field-Strength/Distance Curves

Following previous practice we can derive, for a given time-percentage, the "best fit" line for log E plotted as a function of distance, making the assumption that the field strength E varies with distance d, according to the law

$$E = kd^m$$

where k is a parameter related to the transmission path and m is the slope of the best fit line. In Fig. 3 are shown the field strength plots and the best fit lines for the 0·1%, 1%, 5% and 10% time values. Table 3 gives the values of m and 20 log k for these selected time-percentages. With the exception of the 10% values the slope of the best fit line tends to increase with time-percentage.



CURVE	RECEIVING SITE	DISTANCE km	TOTAL HOURS RECORDED	FREE SPACE FIELD STRENGTH FOR 1kW e.r.p. [dB(µV/m)]
(*a*)	Happisburgh	198	10,809	61
(*b*)	Flamborough Head	365	11,466	55·6
(*c*)	Newton-by-the-Sea	543	11,165	52·2
(*d*)	Bridge of Don	690	11,465	50·2
(*e*)	Lerwick	950	11,493	47·3

Fig. 2 . Variation of field strength with time

TABLE 2

Field Strengths (774 MHz) - October 1961 to December 1963

CURVE	RECEIVING SITE	DISTANCE km	FIELD STRENGTH, dB(µV/m) FOR 1 kW e.r.p.				
			0·1%	1%	5%	10%	50%
(*a*)	Happisburgh	198	79·0	68·0	47·0	31·0	5·5
(*b*)	Flamborough Head	365	64·0	50·5	22·0	7·0	<NL
(*c*)	Newton-by-the-Sea	543	57·0	31·5	1·0*	-9·0*	<NL
(*d*)	Bridge of Don	690	39·0	14·0	<NL	<NL	<NL
(*e*)	Lerwick	950	33·0	5·0*	<NL	<NL	<NL

* Extrapolated

<NL - below noise level

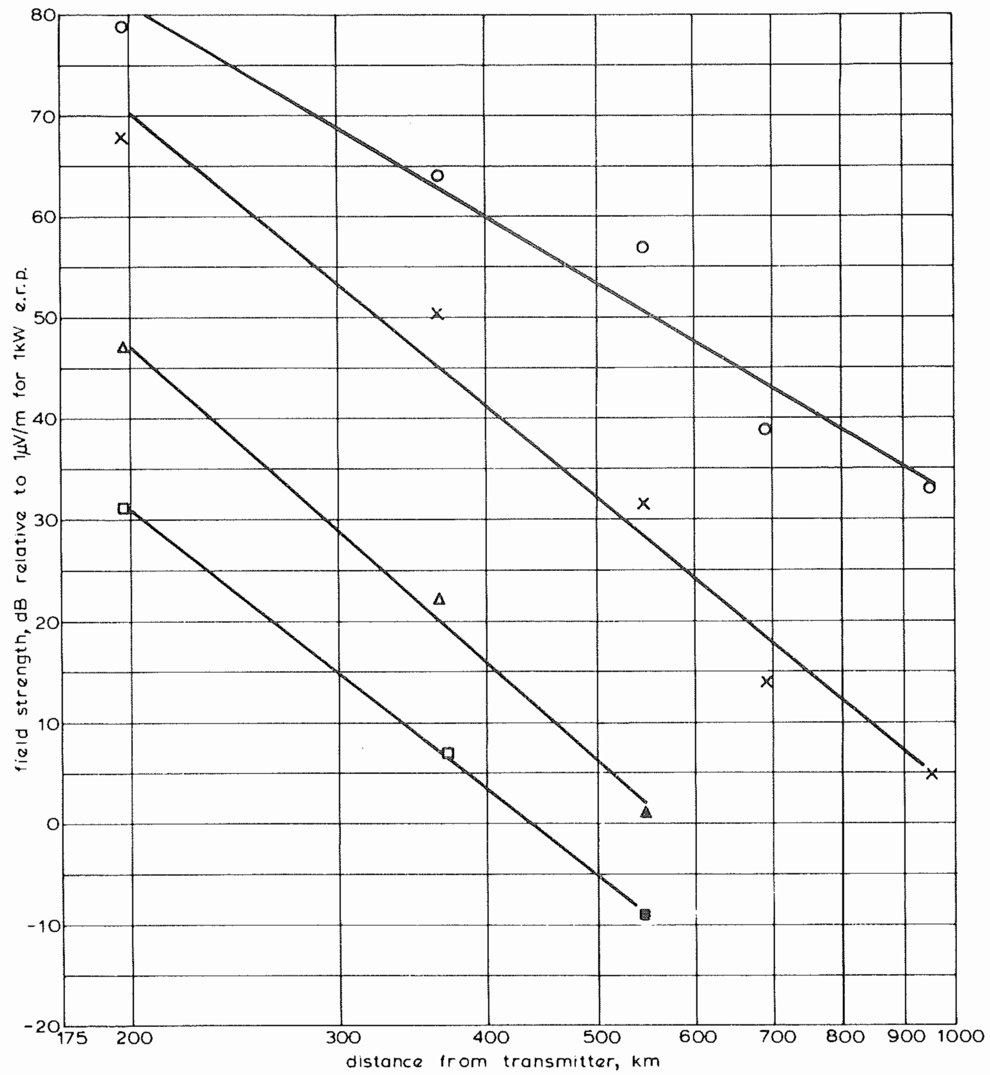


Fig. 3 - Variation of field strength with distance

o 0·1% Time	▲ 5% Time extrapolated
× 1% Time	□ 10% Time
Δ 5% Time	■ 10% Time extrapolated

TABLE 3

Slope of Field-Strength/Distance Lines

TIME-PERCENTAGE	m	20 log k
0·1	-3·464	240·2
1	-4·848	293·8
5	-5·199	286·5
10	-4·557	240·4

3.4. Monthly Field-Strength Variations

The field strengths exceeded each month at Happisburgh and Flamborough Head for selected time-percentages are shown in Figs. 4(*a*) and 4(*b*) respectively. Not all of the Flamborough Head results are shown because some of them are below the noise level of the receiver. It is considered that there is insufficient information to justify production of similar graphs for the other three sites.

Table 4, which is derived from Figs. 4(*a*) and (*b*), shows the overall range of variation in monthly field-strength values for stated time-percentages at Happisburgh and Flamborough Head. It can be seen that the field strengths for low time-percentages have a much greater month-to-month variation than those at the higher percentages. This is to be expected since the latter values correspond to relatively normal propagation conditions. The large monthly variation at low time-percentages emphasises the necessity for data to be obtained over extended periods of time.

An inspection of Figs. 4(*a*) and (*b*) shows that there is a tendency for the signals to be higher during the summer months, and lower during the winter. It is however, of interest to note that the highest monthly field strength values for 0·1%, 1%, 5% and 10% time throughout this series of measurements occurred during a winter month, namely, December 1962. These high values occurred over

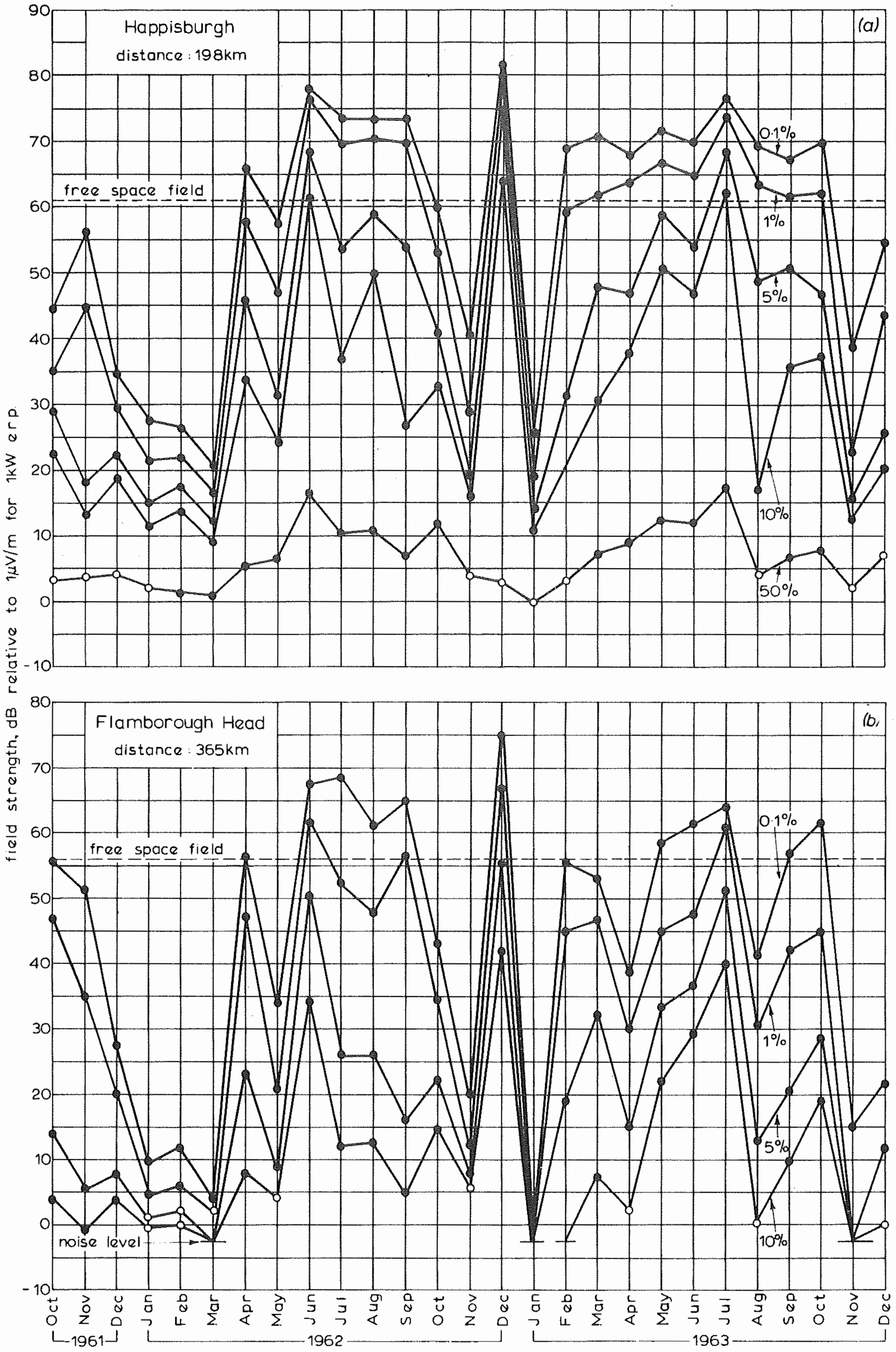


Fig. 4 - Field strengths exceeded in each month for selected time percentages

o Extrapolated value

TABLE 4

Range of Monthly Field Strengths; October 1961 - December 1963

RECEIVING SITE	PATH DISTANCE km	RANGE OF VARIATION OF MONTHLY FIELD STRENGTHS FOR STATED TIME-PERCENTAGES dB				
		0·1%	1%	5%	10%	50%
Happisburgh	198	61·5	64·0	63·0	55·0	17·5
Flamborough Head	365	>78·5	>62·0	>55·5	>37·0	-

the period from 2nd - 5th of December, and can be associated with a large stationary anticyclonic system situated over Central Europe.

4. COMPARISON OF 774 MHz OVERSEA RESULTS WITH OTHER MEASUREMENTS OVER THE SAME PATHS

4.1. Band IV Measurements

The results of measurements of transmissions radiated in Band IV at 560 MHz from Scheveningen, and received at the same five coastal sites, have been described in earlier reports.[3,7] A later series of measurements of this same transmission[8] also utilized the Happisburgh receiving site. Figs. 5(*a*) to (*e*) show, for each of the sites, the field strength/time-percentage curves obtained at 774 MHz, and also those at 560 MHz from these earlier measurements. Before considering the differences due to frequency it is appropriate to first consider the differences between the various Band IV results.

At all sites, except Happisburgh, the field strength at any specified time percentage during the period from June 1959 to June 1961 exceeds that during the period from October 1961 to June 1962 by some 10 - 20 dB. At Happisburgh this situation also exists over the range of time percentages relevant to frequency planning applications, i.e. where co-channel interference may be accepted for between 1% and 10% of the time. However, at this site the two periods tend to provide the same values for large time percentages i.e. under normal propagation conditions, while the second period gives the higher values for low time percentages.

The discrepancy between the two sets of results may be assumed to derive entirely from the occurrence of differing meteorological conditions during the two periods, again emphasising the importance of extending measurements over a long time to obtain representative statistical distributions. It should be noted that the first series of measurements at 560 MHz covered a period of two complete years commencing with the prolonged summer weather of 1959. In the report[3] on these measurements it is suggested that the somewhat exceptional anticyclonic conditions of this summer may have biased the overall results. Furthermore, a month by month comparison of the results from these measurements suggested a seasonal pattern with signals tending to be lower during the winter months. As discussed in Section 3.4 of the present report, the same trend is observed, except for the anomalous results of December 1962, for the 774 MHz transmissions. Consequently it might be expected that the second series of measurements at 560 MHz, which covered a period of 8½ months excluding the summer months, would be lower than the first series. That they should be so much lower is, nevertheless, surprising. The results of the March 1963 to June 1964 measurements (obtained at Happisburgh only) approximate very closely to the result obtained by combining the previous two periods discussed above.

4.2. Comparison of Band IV and Band V Measurements

From Figs. 5(*a*) to (*e*) it may be seen that, at all sites except Happisburgh, the field-strength/time-percentage distribution for the measurements at 774 MHz lies between the distributions for the two series of measurements at 560 MHz. There is, however, a trend for the Band V distribution to approximate more closely to the higher of the two Band IV distributions at the nearer sites and to the lower one at the more distant sites. In other words, for any specified time percentage, the slope of the field-strength/distance characteristic is greater at Band V than at Band IV.

It has been shown in previous simultaneous 560 MHz and 774 MHz oversea measurements[7] that between 200 km and 1000 km the field-strength/distance relationships of the two transmissions at any specified time-percentage are very similar. The maximum value of the ratio between the Band IV and Band V field strengths is about 5 dB. This maximum value, (the Band V field strength being the higher), occurs for low time percentages at short distances. Furthermore, the variation of this ratio with distance does not exceed approximately 3 dB. Consequently, any substantial difference between the slopes of the field-strength/distance characteristics of the consecutive Band IV and

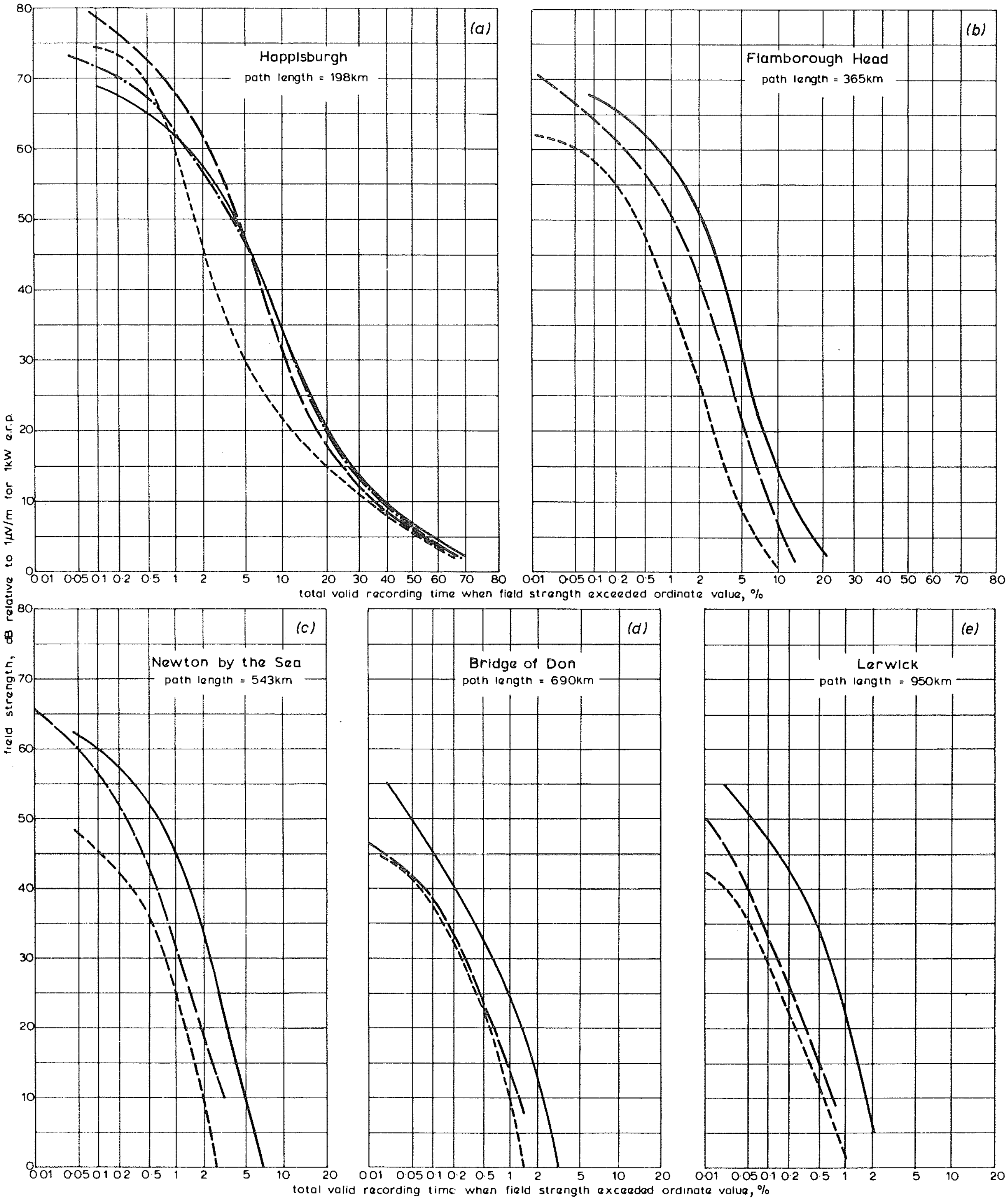


Fig. 5 - Comparison of 560 MHz and 774 MHz field-strength/time-percentage curves for each receiving site

——————— 560 MHz June 1959 - June 1961 — — — — — 560 MHz October 1961 - June 1962

—·—·—·— 560 MHz March 1963 - June 1964 (Happisburgh only) ——— ——— 774 MHz October 1961 - December 1963

Band V measurements may be attributed primarily to differing propagation conditions during the two periods, i.e. to the positions of the anitcyclonic systems relative to the transmission paths.*

The results represented in Figs. 5(*a*) to (*e*), together with the results of the simultaneous recordings in Bands IV and V, indicate that variations between the measurements depend less upon frequency than upon the period of time over which the measurements are made. It therefore appears logical to combine all the results of measurements in Bands IV and V to give single field-strength/time-percentage distributions for the five sites. These resultant curves are plotted in Figs. 6(*a*) to (*e*) and represent total measurement periods of 6¼ years at Happisburgh and 5 years at the other four sites. Results for particular time-percentages are given in Table 5.

4.3. Comparison of U.H.F. and V.H.F. Measurements

Figs. 6(*a*) to (*e*) show for each of the five receiving sites, the combined field-strength/time-percentage curves for Bands IV and V, together with curves derived from previous measurements in Bands II[1] and III.[2] The operating frequencies for these latter measurements were 94·35 MHz and 187 MHz. It may be seen that at the low time-percentages, field strength values increase substantially with increase of frequency. Lerwick results are exceptional in that the Band II curve exceeds the Band III curve by some 1 to 2 dB, but this difference is not considered significant.

The only field-strength/time-percentage curves of Fig. 6 that extend beyond the 5% time value are those for the shorter transmission paths, represented by Figs. 6(*a*) and (*b*). These show that the field strength curves tend towards identical values in the 10% to 20% region, and that the v.h.f. field strengths exceed the u.h.f. values for the greater time-percentages.

5. COMPARISON OF COMBINED BANDS IV AND V MEASUREMENTS WITH CCIR FIELD-STRENGTH/DISTANCE CURVES

5.1. Adjustments Required to Standardize Measured Values

All the results obtained in this and earlier reports were obtained at open coastal sites, the site heights ranging from approximately 9 m to 90 m above mean sea level. For the purpose of calculating co-channel interference probabilities over sea paths, however, it is convenient to use a single series of field-strength/distance curves, representing field strength probabilities in built-up coastal areas for standardized effective transmitting and receiving aerial heights. It is considered that a suitable approximation of the "clutter loss" due to buildings (sometimes called urban depression) may be obtained by reducing the measured values by 7 dB. The currently adopted CCIR oversea curves for u.h.f. propagation[4] refer to transmitting and receiving aerial heights of 300 m and 10 m respectively. For other aerial heights the CCIR recommend[4,9] utilization of a distance correction such that, for a distance x km and transmitting and

TABLE 5

Combined Results of 560 MHz and 774 MHz Measurements

RECEIVING SITE	DISTANCE km	NO. OF MONTHS RECORD AVAILABLE	FIELD STRENGTH, dB(μV/m) FOR 1kw e.r.p. 0·1%	1%	5%	10%	50%
Happisburgh	198	75	75·0	64·0	45·5	30·5	6·0
Flamborough Head	365	59	66·0	53·0	24·0	8·0	<NL
Newton-by-the-Sea	543	59	57·5	37·5	2·5	-6·0*	<NL
Bridge of Don	690	59	42·5	19·0	<NL	<NL	<NL
Lerwick	950	59	42·0	10·5	<NL	<NL	<NL

* Extrapolated

<NL - Below Noise Level

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* It should, however, be noted that both the simultaneous and consecutive series of measurements show that at Happisburgh (198 km) the Band V transmission results in significantly higher field strengths at time percentages of less than 5%.

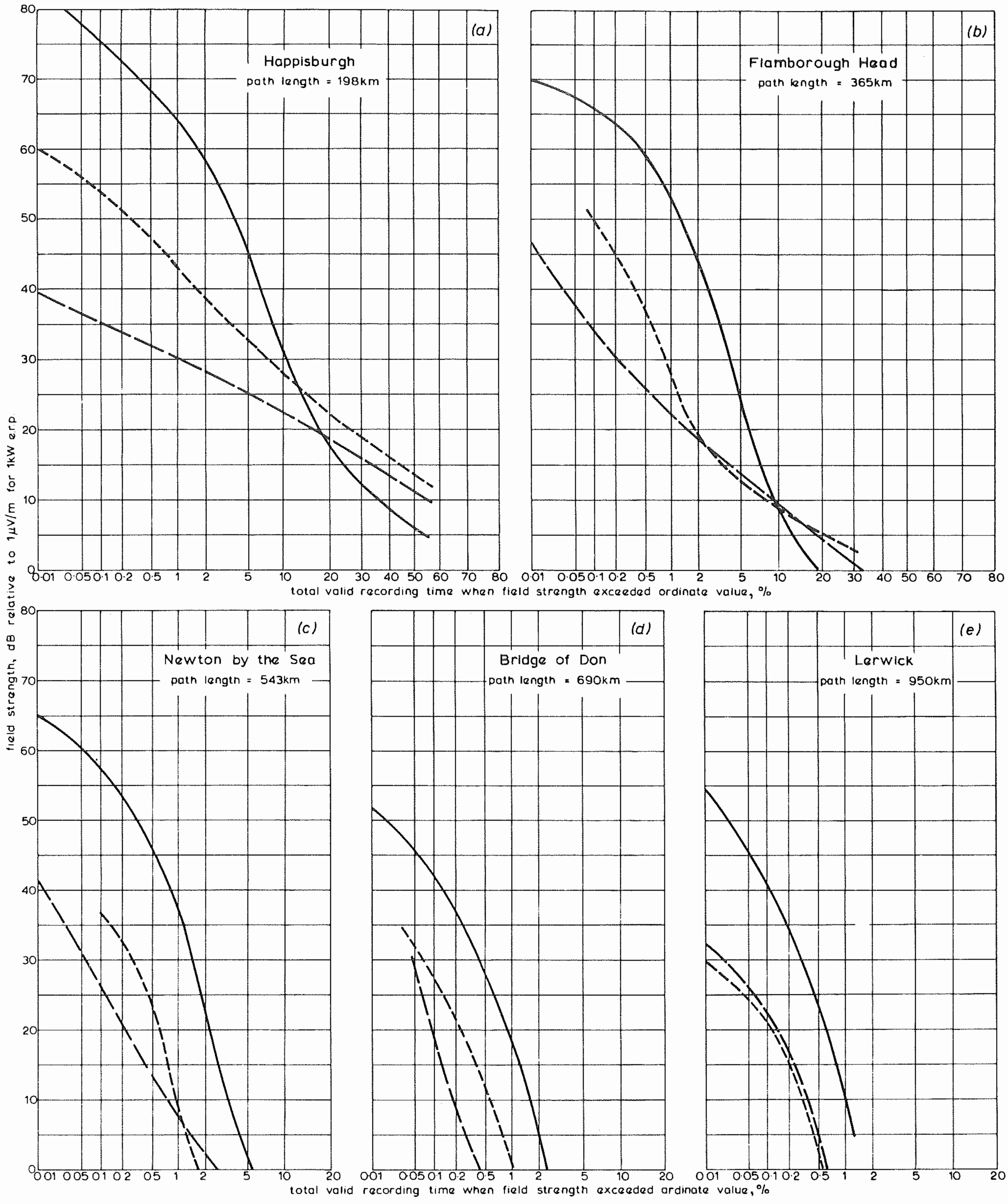

Fig. 6 - Comparison of u.h.f. and v.h.f. field-strength/time-percentage curves for each receiving site

——— Combined Band IV/V results – – – – Band III results (187 MHz) — — — Band II results (94·35 MHz) receiving aerial heights of h_1 and h_2 meters, the curves should be read for a distance of

$$x + 70 - 4{\cdot}1(\sqrt{h_1} + \sqrt{h_2} - \sqrt{10})\ \text{km.}$$

Preliminary results of further measurements being carried out by the BBC indicate that the relationship between field strength and aerial height over sea paths varies according to the propagation conditions. Aerial height-gain appears to be least under the most abnormal propagation conditions. It is therefore proposed that an empirical allowance be made for this varying relationship by applying the full CCIR distance correction at the 10% and and 50% time levels, and no correction at 1% time. For 5% time a correction of half the full value appears to be appropriate.

In Table 6 are given the measured results of Table 5, adjusted by the correction factor for clutter loss, and by the distance correction required to relate these measurements to transmitting and receiving aerial heights of 300 m and 10 m a.m.s.l.

5.2. Comparison Between Existing and Proposed CCIR Curves

Fig. 7 represents current CCIR oversea u.h.f. propagation curves ratified at the Plenary Session, Geneva 1963. Superimposed are the adjusted results given in Table 6. It will be seen that although there is reasonable agreement between the curves and measured values at the shorter distances, discrepancies greater than 10 dB occur for the more distant sites at the 1% and 5% values. The root-mean-square discrepancy for the 12 points available for comparison with the curves is 7·8 dB.

In view of the discrepancies between the measurements and existing CCIR curves, a new series of u.h.f. field-strength/distance curves has been proposed by United Kingdom CCIR Study Group V for adoption by the CCIR at the Plenary Session at Oslo this year. These curves which are based on a number of oversea path measurements, including those made by the BBC, are represented in Fig. 8 with the values from Table 6 superimposed. These curves show an improved correlation with the measurements, the root-mean-square discrepancy being 3·9 dB, i.e. half that for the current curves. The principal discrepancies are at the 1% time-percentage, but they do not exceed 7 dB in any instance. The relatively poor fit of the points to

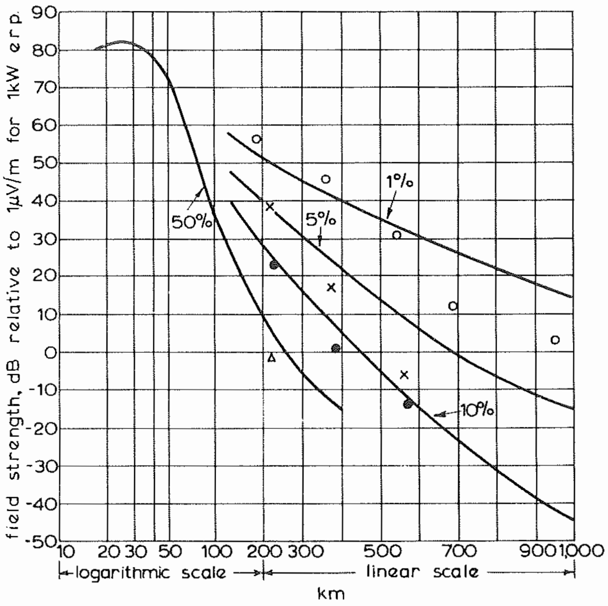

Fig. 7 - CCIR curves for u.h.f. oversea propagation (Geneva 1963)

Measured values from Table 6

- o 1% Time
- x 5% Time
- ● 10% Time
- Δ 50% Time

TABLE 6

Combined Results of 560 MHz and 774 MHz Measurements, Modified to Standard Conditions Represented by CCIR Curves

RECEIVING SITE	TRANSMITTING AERIAL HEIGHT a.m.s.l.	APPROXIMATE RECEIVING AERIAL HT. a.m.s.l.	MAX. DISTANCE CORR$^{\underline{N}}$	ACTUAL DISTANCE	MAX. CORRECTED DISTANCE	FIELD STRENGTH WITH 7 dB CORR$^{\underline{N}}$ FACTOR APPLIED dB(μV/m) FOR 1 kW e.r.p.			
	m	m	km	km	km	1%	5%	10%	50%
Happisburgh	60	25	+30·5	198	228·5	57·0	38·5	23·5	-1·0
Flamborough Head	60	55	+20	365	385	46·0	17·0	1·0	-
Newton-by-the-Sea	60	30	+28	543	571	30·5	-4·5	-13·0*	-
Bridge of Don	60	20	+33	690	723	12·0	-	-	-
Lerwick	60	100	+10	950	960	3·5	-	-	-

* Extrapolated

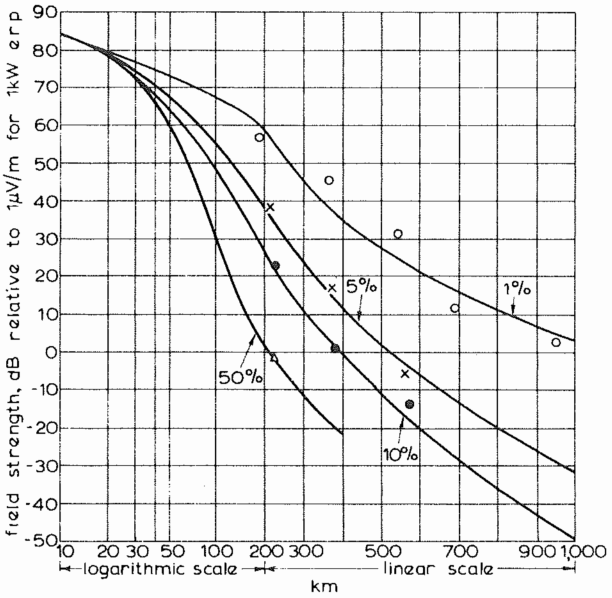

Fig. 8 - CCIR u.h.f. oversea curves: U.K. proposal (1965) for propagation over the North Sea

Measured values from Table 6
o 1% Time
× 5% Time
● 10% Time
Δ 50% Time

this curve may be considered as due either to over-simplification of the corrections required to standardize the measured values, or to an error in the slope of the curve inherent in the assumption of a power-law field-strength/distance relationship. The poor fit of the point representing 10% time at a distance of 571 km may be explained if it is remembered that this point is derived by extrapolation of the original field-strength/time-percentage curve.

6. CONCLUSIONS

The results of the oversea path measurements at 774 MHz represent the latest phase of a continuous programme of measurements over these paths at frequencies in the v.h.f. and u.h.f. bands. Comparison with results already obtained in Band IV show that at any given time-percentage the slope of the field-strength/distance curve may be slightly greater in Band V than in Band IV. However, the position and slope of these curves for low time-percentages depend upon the meteorological conditions which exist over the propagation paths during the measurement periods. It would appear therefore that, in a climate such as is experienced in the United Kingdom, reliable field-strength/distance curves for low time-percentages should be derived from measurements extending over a period of several years. Bearing in mind that the Band IV and Band V results were substantially the same, they may be combined to provide a single series of curves. We thus have results covering a period of about 5 years.

When comparing the results of the measurements with current CCIR oversea curves, appreciable discrepancies are apparent at the greater distances for low time-percentages. These discrepancies are considerably reduced when comparison is made with the curves currently proposed by the United Kingdom CCIR Study Group V. In this instance the only significant discrepancies occur at the 1% time level.

Both Band IV and Band V results show that the month to month variation of field strength increases with decreasing time-percentage. A seasonal trend is indicated, abnormal propagation tending to occur mainly during the summer months. It may be appropriate to consider this seasonal trend when planning co-channel transmitters. If a field strength level is derived from the overall results, for which interference may be expected for a certain percentage of the time, this percentage may be appreciably exceeded during the summer months. However as the results for December 1962 show, extremely high field strength levels may also occur in the winter months.

In view of the requirement for prolonged measurements to establish reliable information about low time-percentage values, it would not appear that any further comparisons with this 1% curve at the greater distances will be readily obtained. However useful further measurements could be carried out to check the CCIR curves at shorter ranges. If such short range measurements could be carried out at frequencies in both Band IV and Band V, the apparent trend towards higher field strength values in Band V at low time-percentages could be further investigated.

7. ACKNOWLEDGEMENTS

The BBC acknowledges with grateful thanks the facilities most willingly provided by the Netherlands Postal and Telecommunications Services and in particular by the staff of Scheveningen Radio who were responsible for installing and maintaining the transmitting systems.

Thanks are also due for the assistance and facilities given by the Superintendent and technical staff at Lerwick Meteorological Observatory. Acknowledgement is also made to the Ministry of Transport for permission to use its coastguard stations and for the valuable help given by the coastguard officers.

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Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey